**NATIONAL TRANSPORTATION SAFETY BOARD**

Office of Aviation Safety
Washington, D.C. 20594

**HUMAN PERFORMANCE**

# Group Chairman's Factual Report

# DCA13MA120

ADDENDUM 2

(22 Pages)

**Simulator Observational Study for Asiana Flight 214 Accident**

**(DCA13MA120)**

| | | |
|---|---|---|
| **Dates** | January 21-23, 2014 | |
| **Device** | Boeing B777 E-Cab in Seattle, Washington | |
| **Time (Approximate)** | Day 1 (Tues): 4-hour pre-brief<br>Day 2 (Wed): 7 hours 52 minutes + 30 minute lunch break<br>Day 3 (Thurs): 2 hour 20 minutes | |
| **In-Cockpit Participants** | NTSB | (2) Ops/HP Group Chairs |
| | Boeing | (1) Ops/HP Group Member |
| | Boeing | (1) B777 Test Pilot 1 |
| | Boeing | (1) B777 Test Pilot 2 |
| | Asiana | (1) Ops/HP Group Member |
| | Asiana | (1) B777 Training Captain |
| | FAA | (1) B777 Test Pilot |
| | TOTAL | (8) |

## Objectives

Allow the NTSB Operations / Human Performance Group to:

1. Evaluate pilot-in-the-loop deceleration and flight path performance of the B777 from different starting positions and identify preferred techniques for executing a stable visual approach to runway 28L at KSFO subject to constraints derived from Asiana and Boeing published guidance and ATC clearances issued to the accident flight crew.

2. Observe pilot-in-the-loop simulations approximating recorded parameters during the accident flight (subject to the angle of attack and sideslip angle limitations of the B777 Engineering Cab simulation model).

3. Observe Asiana simulator training scenarios involving visual approaches to KSFO, a pre-accident version performed by the PF during B777 transition training and a post-accident version that was revised to include a high-energy visual approach.

4. Observe autothrottle automatic engagement.

## Simulator Activities

Simulator motion was not available for this fixed-base device, which was normally used for research. A PAPI displayed adjacent to runway 28L was calibrated to project a glidepath of 2.98 degrees (two reds two whites) with increments of +18 (one red three white lights), +35 (four white lights), -18 (three red, one white light), and -35 (four red lights) minutes of arc. During all runs, simulator time history data was recorded and these data were subsequently provided to the NTSB.

### 1. Evaluation of Pilot-in-the-Loop B777 Deceleration and Path Performance, Subject to Various Constraints

Task: Evaluate pilot-in-the-loop deceleration and flight path performance of the B777 from different starting positions and identify preferred techniques for executing a stable visual approach to runway 28L at KSFO subject to constraints derived from Asiana and Boeing published guidance and ATC clearances issued to the accident flight crew.

*Participants*

Participants included two B777-qualified and current flight crews. The PF for each crew was a test pilot with flight test experience on the B777, one from Boeing and one from the FAA's Seattle, Washington, Aircraft Certification Office. The PM for the first crew was another Boeing test pilot. The PM for the second crew was an Asiana B777 training captain who served on Asiana's B777 training team. The Boeing and FAA test pilots had not flown the B777 in regular air transport line operations, but the Asiana B777 training captain had done so. The two Boeing pilots had flown together previously, but the FAA test pilot and the Asiana B777 training captain had not. Only the Asiana B777 training captain was familiar with Asiana's airline-specific training and procedures.

*Method*

Visual approaches were made to runway 28L at KSFO with the autopilot (AP) off, beginning 5 nautical miles from the displaced runway threshold, as indicated on the navigation display.[1] Approaches continued until the airplane landed or the flying pilot called to terminate the run, at which time the simulation was reset. Multiple observers were able to view test runs from inside and behind the simulator cab.

[1] The NAV display distance on final approach is the direct line distance from the airplane to the displaced runway threshold.

The simulator was programmed to approximate the weight, C.G., and stabilizer setting of the accident airplane at 2,100 feet MSL during the accident approach. These settings are listed below.

| | |
|---|---|
| Weight | 423,360 lbs |
| C.G. | 28.5% m.a.c.[2] |
| Accident stab setting | -3.3° FRL |
| Altimeter Setting | 29.82“ Hg (per CVR) |
| Outside Air Temperature | 17° C (per CVR) |
| Average Wind | 200° (true) @ 8 knots[3] |

Initial conditions for simulator runs were as follows.

| | |
|---|---|
| 1. Altitude | 1,650 feet MSL (standard profile) or 2,100 feet MSL (accident profile) |
| 2. Position: | On the runway 28L localizer 5 nautical miles from the displaced runway threshold (as indicated on the navigation display) |
| 3. Airspeed: | 180 KCAS (standard profile) or 175 KCAS (accident profile) |
| 4. Flap setting: | 5 |
| 5. Landing gear: | Down |
| 6. Autoflight system modes: | SPD - LOC - V/S |
| 7. Approach in FMS | ILS or LOC Z Runway 28L |
| 8. Autopilot: | Off |
| 9. Autothrottles: | Armed and engaged |
| 10. Flight director | Left FD off, right FD on (Except for conditions 1.4b and 1.8 b, where both FDs were on) |
| 11. Engine RPM | Default setting (standard profile) or approximately 42% N1 (accident profile) |
| 12. Speed bug | 172 knots |
| 13. Descent rate | 850 fpm (standard profile) or 1,000 fpm (accident profile) |

[2] CG was calculated from dispatch information and fuel burn estimates. Stabilizer position was from the FDR.
[3] This wind value was an average of values recorded by the FDR during final approach.

Test conditions were defined as follows.

| | Condition # | Use of Speedbrakes Allowed? | Throttle Lever Manual Override Allowed? | Brief Description |
|---|---|---|---|---|
| **Standard Profile Initial Conditions:**<br><br>Altitude 1,650 feet (MSL)<br><br>Airspeed 180 KCAS<br><br>-850 FPM | 1.1 | No | No | No speedbrakes or manual throttle override allowed |
| | 1.2 | No | Yes | Speedbrakes not allowed, manual throttle override allowed |
| | 1.3 | Yes | No | Speedbrakes allowed, manual throttle override not allowed |
| | 1.4a | Yes | Yes | Speedbrakes and manual throttle override allowed |
| | 1.4b | Yes | Yes | Speedbrakes and manual throttle override allowed, plus VNAV engaged and both FDs on |
| **Accident Profile Initial Conditions:**<br><br>Altitude 2,100 feet (MSL)<br><br>Airspeed 175 KCAS<br><br>-1,000 FPM | 1.5 | No | No | No speedbrakes or manual throttle override allowed |
| | 1.6 | No | Yes | Speedbrakes not allowed, manual throttle override allowed |
| | 1.7 | Yes | No | Speedbrakes allowed, manual throttle override not allowed |
| | 1.8a | Yes | Yes | Speedbrakes and manual throttle override allowed |
| | 1.8b | Yes | Yes | Speedbrakes and manual throttle override allowed + VNAV engaged and both FDs on |

Timing of changes in flap configuration to flaps 20 and flaps 30 was at pilot discretion (subject to compliance with placarded flap speeds) and was to be done in a manner that facilitated deceleration to 137 (+10/-5 knots) and being on the glidepath by 500 feet. In addition, pilots were asked to comply with the following constraints during the approach:

- Placarded flap speeds: 5/235, 15/215, 20/195, 25/185, and 30/170.
- Asiana (POM 2.1.6.2) and Boeing (FCTM Section 1.34) guidance to use the autothrottles during approach.
- Asiana (POM 2.12.9.7) and Boeing (FCTM Section 4.22) guidance that, “To avoid buffeting, use of speedbrakes with flaps greater than 5 should be avoided.”
- Asiana (POM 2.12.9.7) and Boeing (FCTM Section 4.22) guidance that “speedbrakes should be retracted before reaching 1,000 feet AGL.”

- Asiana FOM (7.8.9) instruction to avoid descent rates exceeding 1,500 fpm between 2000 and 1,000 feet AGL, and descent rates exceeding 1,000 fpm below 1,000 feet AGL.

On day 1, the two B777 qualified and current crews participated in a 4-hour pre-briefing period. On day 2, both crews performed practice runs, received a break, and then performed test runs. The planned order of all runs is listed in the table below. Crews were able to repeat runs upon request.

After the B777 current and qualified crews completed all test runs, the co-chairs of the NTSB Operations / Human Performance Group obtained hands-on experience with each of the test conditions by flying them from the left pilot seat.

*Planned Order of Practice and Test Runs*

| Run# | Cond-ition | Boeing B777 Test Pilot 1 | Boeing B777 Test Pilot 2 |
|---|---|---|---|
| P1 | 1.1 | PF | PM |
| P2 | 1.2 | PF | PM |
| P3 | 1.3 | PF | PM |
| P4 | 1.4a | PF | PM |
| P5 | 1.4b | PF | PM |
| P6 | 1.5 | PF | PM |
| P7 | 1.6 | PF | PM |
| P8 | 1.7 | PF | PM |
| P9 | 1.8a | PF | PM |
| P10 | 1.8b | PF | PM |
| Break | | | |
| 1 | 1.1 | PF | PM |
| 2 | 1.2 | PF | PM |
| 3 | 1.3 | PF | PM |
| 4 | 1.4a | PF | PM |
| 5 | 1.4b | PF | PM |
| 6 | 1.5 | PF | PM |
| 7 | 1.6 | PF | PM |
| 8 | 1.7 | PF | PM |
| 9 | 1.8a | PF | PM |
| 10 | 1.8b | PF | PM |

| Run# | Cond-ition | FAA B777 Test Pilot | Asiana B777 Training Captain |
|---|---|---|---|
| P1 | 1.1 | PF | PM |
| P2 | 1.2 | PF | PM |
| P3 | 1.3 | PF | PM |
| P4 | 1.4a | PF | PM |
| P5 | 1.4b | PF | PM |
| P6 | 1.5 | PF | PM |
| P7 | 1.6 | PF | PM |
| P8 | 1.7 | PF | PM |
| P9 | 1.8a | PF | PM |
| P10 | 1.8b | PF | PM |
| Break | | | |
| 1 | 1.1 | PF | PM |
| 2 | 1.2 | PF | PM |
| 3 | 1.3 | PF | PM |
| 4 | 1.4a | PF | PM |
| 5 | 1.4b | PF | PM |
| 6 | 1.5 | PF | PM |
| 7 | 1.6 | PF | PM |
| 8 | 1.7 | PF | PM |
| 9 | 1.8a | PF | PM |
| 10 | 1.8b | PF | PM |

Note: Run numbers beginning with the letter “P” were practice runs.

The human performance group chairman served as test conductor and observed all runs from the center jumpseat in the simulator cab. The operational factors (ops) group chair and others also observed from inside or just behind the simulator cab. For a description of recorded data, see Appendix 1 of this report.

During pre-briefing, test pilots objected to the constraint that they should avoid use of speedbrakes with flaps greater than 5. They stated that the complete guidance in the Boeing FCTM (4.22) included the sentence “If circumstances dictate the use of speedbrakes with flaps extended, high sink rates during the approach should be avoided.” They said this wording meant that the speedbrakes could be used at flap settings higher than 5. The B777 training captain stated, however, that Asiana pilots

avoided the use of speedbrakes with flaps greater than 5. Therefore, in order to be consistent with Asiana guidance, crews were asked to avoid the use of speedbrakes with flaps greater than 5.

After simulator runs began, the test conductor noticed that (during practice runs and first two test runs), the first crew was consistently selecting flaps 25 as an intermediate setting between flaps 20 and flaps 30 to aid deceleration. According to the Asiana B777 training captain, standard procedure at Asiana airlines was to transition directly from flaps 20 to 30. Boeing pilots stated that use of flaps 25 was not discouraged by any Boeing guidance, however crews were asked to avoid using flaps 25 during test runs to be more consistent with Asiana standard operating procedures and they complied with this instruction. The first crew avoided use of flaps 25 during remaining test runs (3-10) and the second crew complied with this constraint during all practice and test runs.

*Evaluation and Results*

Data from practice and test runs were evaluated to determine the altitude by which the airplane was stabilized for each run and to determine whether the approach was stable at (and below) 500 feet AGL. Stable criteria were based on parameters described in the Asiana Airlines POM (section 2.13.6), and they were operationalized as follows.

1) Glide path

   Glidepath was evaluated by calculating the approximate pilot eye height position (arctangent of {(radar altitude plus a constant of 35 feet) divided by the horizontal distance from the airplane to the PAPI (distance to the displaced threshold plus 1366.5 feet)} and determining whether this angle was within the range that would have resulted in an acceptable PAPI indication (either 2 reds 2 whites, 1 red 3 whites, or 3 reds 1 white).[4]

2) Airspeed

   Airspeed was examined to determine if it was within +10 / -5 knots of the approach speed (137 knots).

3) Vertical speed

   Vertical speed was examined to determine if it was no more than -1,000 feet per minute.

4) Flap setting

   Flap configuration was examined to determine if flaps were in the landing configuration (flaps 30).

[4] Approach angles of 2.98 degrees +/- 0.58 degrees would have resulted in an acceptable range of PAPI indications.

5) Thrust setting

Thrust resolver angle was examined to determine if the throttle levers were positioned above approach idle.

A separate evaluation was performed to determine if crews complied with Asiana FOM (7.8.9) guidance to avoid descent rates exceeding -1,000 fpm below 1,000 feet AGL and -1,500 fpm between 2000 and 1,000 feet AGL. This separate evaluation did not affect the judgment about whether an approach was stable at (and below) 500 feet. Results for each crew are summarized in the tables below.

**Results for the first crew.**

| Run# | Cond-ition | Boeing B777 Test Pilot 1 | Boeing B777 Test Pilot 2 | Stable by Altitude (Approx) | Stable at (and Below) 500 feet? | Exceed-ance | Speed (KCAS) at 500 feet MSL | Asiana Max Descent Rate Guidance Respected? | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Between 2,000 and 1,000 feet | Below 1,000 feet |
| 1 | 1.1 | PF | PM | 900 | Yes | | 136 | Yes | Yes |
| 2 | 1.2 | PF | PM | 1000 | Yes | | 137 | Yes | Yes |
| 3 * | 1.3 | PF | PM | 850 | Yes | | 138 | Yes | Yes |
| 4 | 1.4a | PF | PM | 850 | Yes | | 137 | Yes | Yes |
| 5 | 1.4b | PF | PM | 1000 | Yes | | 137 | Yes | Yes |
| 6 | 1.5 | PF | PM | 300 | **No** | A,B,C | 158 | Yes | No |
| 7 | 1.6 | PF | PM | 750 | Yes | | 137 | No | No |
| 8 ** | 1.7 | PF | PM | 400 | **No** | A | 142 | No | No |
| 9 | 1.8a | PF | PM | 500 | Yes | | 139 | Yes | No |
| 10 | 1.8b | PF | PM | 500 | Yes | | 138 | No | No |

Note: *Although run 3 (condition 1.3) allowed for use of speedbrakes, the crew did not use them. ** During run 8, the crew used speedbrakes between about 2,100 and 1,400 feet MSL at flaps at 5. Parameter Exceedance Codes: A = Vertical speed exceeded -1,000 feet per minute, B = Airspeed was more than 10 knots above approach speed, C = Throttle levers were at the idle position.

**Results for the second crew.**

| Run# | Cond-ition | FAA B777 Test Pilot | Asiana B777 Train-ing Captain | Stable by Altitude (Approx) | Stable at (and Below) 500 feet? | Exceed-ance | Speed (KCAS) at 500 feet MSL | Asiana Max Descent Rate Guidance Respected? | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Between 2,000 and 1,000 feet? | Below 1,000 feet? |
| 1 | 1.1 | PF | PM | 900 | Yes | | 137 | Yes | Yes |
| 2 | 1.2 | PF | PM | 950 | Yes | | 137 | Yes | Yes |
| 3 | 1.3 | PF | PM | 1000 | Yes | | 137 | Yes | Yes |
| 4 * | 1.4b | PF | PM | 800 | Yes | | 137 | Yes | Yes |
| 5 | 1.5 | PF | PM | 500 | Yes | | 137 | No | No |
| 6 | 1.6 | PF | PM | 600 | Yes | | 137 | No | No |
| 7 ** | 1.7 | PF | PM | N/A*** | **No** | A, D | 138 | Yes | No |
| 8 **** | 1.8a | PF | PM | 600 | Yes | | 137 | No | No |
| 9 † | 1.8b | PF | PM | 450 | **No** | A | 133 | Yes | No |

Note: * The PF decided to skip condition 1.4a, stating that he would not fly it any differently than condition 1.3. ** During run 7 the crew briefly used the speedbrakes about 2,000 feet MSL at flaps 20. *** Run 7 was never stable below 500 feet, due to being above glidepath. **** During run 8 the crew briefly used the speedbrakes about 2,000 feet MSL with flaps at 30. † During run 9 a low airspeed excursion (more than 5 knots below approach speed) occurred between about 900 and 550 feet MSL (see footnote 7). Parameter Exceedance Codes: A = Vertical speed exceeded -1,000 feet per minute, D = Airplane too far from the specified glidepath (4 white PAPI lights).

Data indicated that neither crew had difficulty achieving a stable approach in the standard profile conditions (1.1 – 1.4b), and that both crews experienced more difficulty in the high start conditions (1.5 – 1.8b), especially conditions 1.5, 1.7, and 1.8b. This was consistent with pilot comments.

Pilots reported that it was relatively easy to get the airplane configured and stabilized by 500 feet and that no special techniques were required in the standard profile conditions. Pilots said it was more challenging to get configured and stabilized in the high start conditions.

Pilots commented that the VNAV path pointer and deviation scale (located on the navigation display) were easy to use and quite helpful for intercepting and maintaining the desired glide path.

The FAA test pilot said he found high start conditions 1.5-1.8a easier if he focused first on decelerating (by minimizing thrust and configuring to flaps 30 as soon as possible) and second on capturing the glidepath. He termed this the “slow down before go down” technique. He also found the optional Flight Path Vector (FPV) (located on the PFD), and the altitude range arc (located on the navigation display) quite useful. He stated that he used the FPV to maintain real-time awareness of the airplane’s descent angle. After he accomplished deceleration, airspeed stabilization, and flap configuration using the “slow down before go down” technique, he set the MCP altitude to 0 feet and used the altitude range arc to see where the airplane would reach 0 feet. However, he and others commented that using the altitude range arc in this manner would require changes to existing pilot training and procedures.

Data indicated that, in the high start conditions, crews routinely exceeded Asiana maximum descent rates below 2,000 and 1,000 feet AGL (FOM Section 7.8.9). Pilots stated that exceeding these maximum descent rates made it much easier to achieve a stable approach by 500 feet in the high start conditions. They commented that the maximum descent rates were overly restrictive above 500 feet and did not reflect how the airplane was actually flown. Some pilots commented that attempting to comply with the maximum sink rates in the high start conditions required a high degree of pilot attention to sink rate, prevented them from making aggressive early corrections to the flight path, and delayed stabilization. One pilot said it was considered acceptable in type rating training to temporarily exceed such maximum descent rate guidelines if the flightcrew was aware of the high descent rate, communicated their awareness, and made a timely correction back to the normal glidepath.

Data indicated that the first crew only used speedbrakes during test run 8 (between about 2,100 and 1,400 feet MSL). This use occurred entirely at the flaps 5 setting. The second crew only used speedbrakes during test runs 7 and 8 (about 2,000 feet MSL) and this use occurred at flap settings greater than 5 (run 7 flaps 20 and run 8 flaps 30). Pilots stated that the speedbrakes were less effective if they could not be used at flap settings greater than 5. The Boeing test pilots stated that Boeing guidance allowed pilots discretion to use speedbrakes at flap settings higher than 5 and they stated that the FCTM guidance to avoid using the speedbrake at higher flap settings was solely for

passenger comfort, not for respecting airplane structural (safety) limitations. Pilots stated that delaying flaps 20 until after speedbrake use meant less drag and less effective deceleration. Pilots reported that use of the speedbrakes was sometimes also impeded by the autothrottle advancing the thrust above idle in V/S and SPD modes, resulting in drag and thrust being in use simultaneously. Given the constraints imposed on the test runs, pilots concluded that extending flaps 20 as early as possible led to more effective deceleration than using the speedbrakes. Pilots commented that speedbrakes would be more effective if used earlier in the approach, above the starting point for the test runs.

Pilots reported that for the high start conditions it was important to minimize thrust in order to facilitate deceleration but this was difficult to achieve in V/S – SPD modes because when the MCP airspeed was set to the maneuvering speed for each flap setting the autothrottle tended to add power as the airspeed approached the selected speed.[5] Pilots reported that, although nonstandard practice, setting the speed below the flap maneuvering speed (but above the amber band) for each flap setting reduced the tendency for the throttle levers to advance, and this permitted more constant deceleration.

Data indicated that, during manual throttle override (condition 1.6) both PFs were sometimes late to release the throttle levers upon reaching the target speed, resulting in the airspeed briefly decreasing a couple of knots below approach speed.

Pilots reported that selecting VNAV greatly eased the pilot's task for test runs that began on the normal glidepath but it increased workload in the high start conditions. When the airplane was too far above the computed glidepath, the AFDS pitch mode transitioned from VNAV PATH to VNAV SPD and the FD pitch bar began targeting the selected airspeed rather than computed glidepath. If the PF followed the FD pitch bar they tended to deviate from the computed glidepath. If the PF disregarded the FD pitch bar they tended to deviate from the desired airspeed. As the airplane approached the desired glidepath, the pitch mode transitioned back to VNAV PATH again. This led to difficulties controlling airspeed, descent rate, and vertical path.[6] Pilots agreed that briefing and using VNAV was an excellent strategy at the beginning of a visual approach, but selecting VNAV late in the approach was not recommended, especially if the airplane was fast and well above the computed glidepath.

Data indicated that the PFs' use of pitch trim varied across test runs for both crews. For some runs, airspeed and pitch trim reference speed were closely aligned. However, the

[5] The B777 FCOM (p. 1.4) states: "The flap maneuver speed is the recommended operating speed during takeoff or landing operations. These speeds guarantee full maneuver capability or at least 40° of bank (25° of bank and 15° overshoot) to stick shaker within a few thousand feet of the airport altitude."

[6] When the second crew was utilizing VNAVand following the Flight Director (FD) pitch commands in VNAV SPD mode in run 9 (condition 1.8b), the airspeed decreased 7 knots below approach speed. The PF stated afterward that he had followed the FD bars precisely. He speculated that the FD had commanded a slow speed due to idle thrust state (maximizing rate of descent to correct to the glidepath) in combination with a conflict between VNAV SPD mode's algorithm to hold speed and anticipate a future correction to stabilize on the VNAV glidepath.

maximum difference between the airspeed and pitch trim reference speed was about 40 KCAS at 1,100 feet MSL for the first crew (run 1, condition 1.1) and about 25 KCAS at 1,800 feet MSL for the second crew (run 6, condition 1.6). The maximum difference below 500 feet MSL was about 30 KCAS for the first crew (run 9, condition 1.8a) and 12 KCAS for the second crew (run 5, condition 1.5).

## 2. Pilot-in-the-Loop Simulations Approximating the Accident Flight

Task: Allow all parties and members of the NTSB Operations / Human Performance Group to observe pilot-in-the-loop simulations attempting to approximate recorded parameters during the accident flight.

The simulator was programmed with initial conditions that approximate the accident scenario as closely as possible. Initial conditions are listed below:

| | |
|---|---|
| Weight | 423,360 lbs |
| C.G. | 28.5% m.a.c. |
| Accident stab setting | -3.3° FRL |
| Altimeter Setting | 29.82“ Hg (per CVR) |
| Outside Air Temperature | 17° C (per CVR) |
| Surface Wind | 200° (true) @ 8 knots |
| | |
| Condition 2.1: | On the runway 28L localizer, 13 nautical miles from the displaced runway threshold, 4,580 feet MSL, 211 KCAS |
| Autopilot | On |
| Autothrottles | Armed and engaged |
| Engine RPM | Default for standard profile |
| Thrust Mode | HOLD[7] |
| Roll Mode | LOC |
| Pitch Mode | FLCH SPD |
| MCP altitude | 1,800 feet MSL (per FDR) |
| MCP airspeed | 192 KCAS (per FDR) |
| Flap setting | 1 |
| Landing gear | Up |
| Event time | 11:23:30.7 (approx.) |
| | |
| Condition 2.2: | On the runway 28L localizer, 5 nautical miles from the displaced runway threshold, CG height 2,100 feet MSL, 175 KCAS |
| Autopilot | On |
| Autothrottles | Armed and engaged |
| Engine RPM | Approximately 42% N1 |
| Thrust Mode | SPD |

[7] Pilot intervention was required to achieve HOLD mode after the simulation became active.

| | |
|---|---|
| Roll Mode | LOC |
| Pitch Mode | V/S |
| MCP altitude | 3,000 feet MSL (per FDR) |
| MCP airspeed | 172 KCAS (per FDR) |
| Flap setting | 5 |
| Landing gear | Down |
| Event time | 11:25:56 (approx.) |

Operations / Human Performance Group members seated in the B777 E-Cab observed approximations of the last 13 nautical miles and the last 5 nautical miles of the accident flight flown by a Boeing test pilot and the NTSB Ops Group Chair with the aid of cue cards and observer prompts. These prompts were based on FDR and CVR information. The PFs attempted to match the following FDR parameters during these runs:

1. Autopilot engagement
2. Autoflight system (AP/ FD/AT) mode settings
3. MCP target settings (airspeed, vertical speed, altitude, and heading)
4. Landing gear handle position
5. Thrust lever positions
6. Trim setting
7. Flap lever position
8. Ground track
9. Altitude time history
10. Airspeed time history

Boeing provided a near real-time graphical means (Boeing Pegasus batch plot capability) to compare parameters flown with the accident time history. This information was reviewed during breaks by the NTSB aircraft performance group chairman.

Runs beginning at the first starting position (condition 2.1) lasted approximately 4 minutes 20 seconds each. Runs that began at starting position 2 (condition 2.2) lasted about 2 minutes each.

Test runs were ordered and crewed as shown below.

| Run# | Condi -tion | Boeing B777 Test Pilot 2 | Asiana B777 Type-Rated Pilot (Ops) | FAA B777 Test Pilot | NTSB Group Chair (Ops) | Asiana B777 Training Captain |
|---|---|---|---|---|---|---|
| 1 | 2.1 | PF | | | | PM |
| 2 | 2.2 | PF | | | | PM |
| 3 | 2.1 | PM | | | | PF |
| 4 | 2.2 | PM | | | | PF |
| 5 | 2.1 | | PM | PF | | |
| 6 | 2.2 | | PM | PF | | |
| 7 | 2.1 | | PF | PM | | |
| 8 | 2.2 | | PF | PM | | |
| 9 | 2.1 | | PM | | PF | |
| 10 | 2.1 | | PM | | PF | |

The human performance group chairman served as test conductor and observed all runs from the center jumpseat. The Ops group chair and others also observed.

Recorded data indicated that none of the runs precisely matched the accident flight. However, some runs closely approximated one or more parameters.

### 3. Familiarization with Asiana Visual Approach Training Scenarios

Task: Allow the NTSB Operations / Human Performance Group to observe Asiana simulator training scenarios involving visual approaches to KSFO, a pre-accident version that was performed by the PF during B777 transition training and a post-accident version that was revised to include a high-energy visual approach.

An Asiana B777 training captain and another Asiana pilot who was type-rated on the B777 demonstrated the scenarios. The pre-accident visual approach procedure (condition 3.1) was demonstrated per the airline's procedures as they existed during the PF's B777 transition training in May/June 2013. The post-accident scenario (condition 3.2), which was described as a "high energy visual approach" was demonstrated per the airline's procedures as revised in November 2013. A handout describing these two different approach scenarios was provided by the Asiana B777 training captain and is included in Appendix 2 of this report.

| Condition # | Approach Type | Location | Contained in Asiana Lesson# |
|---|---|---|---|
| 3.1 | Visual Approach | KSFO | FFS #6 |
| 3.2 | High Energy Visual Approach | KSFO | New FFS #6 and B777 recurrent training |

Runs were ordered and crewed as shown below. The human performance group chair served as test conductor and observed all runs from the center jumpseat. The operations group chair and others also observed.

| Run# | Condition | Asiana B777 Training Captain | Asiana B777 Type-Rated Pilot (Ops) |
|---|---|---|---|
| 1 | 3.1 | PF | PM |
| 2 | 3.1 | PF | PM |
| 3 | 3.2 | PF | PM |
| 4 | 3.2 | PF | PM |
| 5 | 3.2 | PF | PM |

For condition 3.1, there were two runs. Flights were initiated at a point abeam the runway threshold on downwind at an altitude of 1,500 feet and an airspeed of 172 knots, about 2 NM south of the runway. The AP and autothrottle were engaged and the FMA initially displayed SPD – HDG – ALT modes. The PF entered 2 NM and 3NM rings around the threshold in the FMC fix page and used the ND to visualize his position relative to the runway. He extended the final course from the threshold in the FMC for use as a reference. He set up the FMC so that the VNAV path pointer would be visible

on the navigation display. He used timing (assisted by the PM) to decide when to configure and initiate his descent. He began the descent by selecting V/S mode and a vertical speed of -300 to -500 fpm. He used timing to initiate the turn to base leg (executed using TRK SEL). When turning base he selected a vertical speed of -500 to -900 fpm. He completed the landing checklist on base leg. He used visual contact with the runway and the turn prediction display on the ND to assist him with intercepting the final approach course (also accomplished using TRK SEL). He intercepted the final approach course about 3 nautical miles from the runway. He used the VNAV path pointer to determine his position above or below the computed glidepath for the remainder of the approach. He used the MCP heading and vertical speed selectors to control the airplane until 1,000 feet or below, at which time he commanded “manual flight”, disconnected the AP, commanded both FDs off and the right FD on, and then hand-flew the rest of the approach with a vertical speed of 700-900 fpm. Prescribed PM callouts included “1,000” and “500” feet. PF responses were “checked” and “stabilized”, respectively.

For condition 3.2, there were 3 runs. These runs also began with the AP and autothrottle engaged. They were commenced at an altitude of 6,000 feet and airspeed of 180 knots. The starting position was a point located 12 NM south of the airport on a track that was closely aligned with the extended runway centerline. The first run was flown using VNAV mode and the second and third runs were flown using FLCH and V/S modes.

In the first run, the AFDS started in SPD – LNAV – ALT modes with the AP on. The PF selected 1,800 in the MCP altitude window and initiated a descent in FLCH, extended the landing gear, raised the speedbrakes, and descended at over 2,000 fpm. After establishing the descent, he changed the pitch mode to VNAV. As a result, VNAV SPD was displayed on the FMA. When approaching the FAF, the PF stated “Approaching glide path and airport in sight” and he set the MCP altitude to the missed approach altitude. As the airplane approached the computed glidepath, VNAV PATH was displayed on the FMA and the glide path was captured. The PF then stowed the speedbrakes and set the present speed in the MCP speed window (which had blanked with the activation of VNAV PATH). The PF then configured for landing and completed the landing checklist. The PM made "1,000" call-out (PF: "checked"). He then disengaged the AP and flew the rest of the approach manually with the F/D. The PM made "500" call-out (PF: “stabilized”).

In the second and third runs, the AFDS started in SPD – LOC – ALT modes with the AP on. The PF then selected 1,800 in the MCP altitude window, selected “FLCH”, extended the landing gear and raised the speedbrakes, and descended at over 2,000 fpm. Upon reaching 2,800 feet, he selected V/S mode and adjusted the selected vertical speed to intercept the calculated glidepath represented on the VNAV path pointer. Upon reaching the FAF, the PF set the missed approach altitude, stowed the speedbrakes, configured for landing, and completed the landing checklist. About 1,200 feet, the PF disengaged the AP and flew the rest of the approach manually with the autothrottle in SPD mode.

Prescribed PM callouts were “Passing FAF, 1800 feet” (PF: “checked”), “1,000” (PF: “checked”), “minimum” (PF: “Landing, manual flight”) and “500” (PF: “stabilized”).

### 4. Observation of Autothrottle Automatic Engagement

Task: Observe the airspeed targeted by the AFDS after autothrottle automatic engagement.

| Order | Run# | Condition | NTSB Ops Group Chair | Asiana B777 Type-Rated Pilot (Ops) |
|---|---|---|---|---|
| 81 | 1 | 4.1 | PF | PM |

From a position at 1800 feet, configured with gear down and 30 flaps, with the autothrottle armed but not activated, and the airplane being manually flown in level flight, the thrust levers were placed at idle and airspeed was allowed to bleed off to the point where the speed protection system was activated and autothrottle “wakeup” occurred. Autothrottle “wakeup” activated at a point about midway down in the amber band on the airspeed display (about 122 knots), slightly after the activation of the master caution and low airspeed alert. Power was automatically advanced to increase airspeed above the amber band and airspeed was automatically stabilized at the MCP-selected speed of 137 knots.

# APPENDIX 1: DATA RECORDING

*Test Log*

A written test log was kept for each run by NTSB and Boeing personnel, noting date, time, condition #, occupants of left and right seats, pilot flying, pilot monitoring, and data file name and run number (if applicable). Airspeed and distance to airport at 500 feet was recorded. Pilot comments were recorded in writing on prepared comment forms by the test conductor following the completion of each test run. Some participants provided additional written observations to the test conductor after testing had been completed.

*Electronic Data Files*

Simulator data were also recorded in an electronic file. A run number and other means of identifying the recorded data with the runs noted in the run log were included in the electronic file. Recorded parameters are listed at the end of this test plan.

*List of Simulator Parameters for Recording*

<u>Case Identification</u>

Date
Time
Case Number

<u>Time</u>

Elapsed Time (seconds)

<u>Aircraft Configuration</u>

Weight (lbs)
x CG position {% MAC from reference point; define ref. point (e.g., wing leading edge)}
y CG position
z CG position
Ixx (slugs*ft$^2$)
Iyy (slugs*ft$^2$)
Izz (slugs*ft$^2$)
Ixz (slugs*ft$^2$)
Flap position
Gear position

Aircraft Position

Latitude
Longitude
Pressure Altitude (ft)
Radar Altitude (ft)
North distance from a defined reference point (ft)
East distance from a defined reference point (ft)
Distance to runway displayed on NAV
DME distance displayed on PFD

Aircraft Orientation

Yaw angle (deg) (Aircraft true heading)
Pitch angle (deg)
Roll angle (deg)

Aircraft Motion -Relative to Earth

Groundspeed (kts)
Track Angle (deg)
Rate of Climb (ft/min)
Flight path angle (deg)

Aircraft Motion - Relative to Air

Calibrated Airspeed (kts)
True Airspeed (kts)
Mach number
Dynamic Pressure (PSF)
Angle of Attack (deg)
Angle of Sideslip (deg)

Aircraft Motion - Angular Rates

P (deg/s) (body axis roll rate)
Q (deg/s) (body axis pitch rate)
R (deg/s) (body axis yaw rate)

Aircraft Motion - Accelerations

nx (g's) (load factor along body x axis)
ny (g's) (load factor along body y axis)
nlf (g's) load factor = Lift/Weight (for airplane CG)
nlf (g's) load factor = Lift/Weight (for pilot station)

Pilot Control Positions

Column position (deg)
Control wheel position (deg)
Rudder pedal position (deg)
Throttle lever position (deg)
Speedbrake Handle Position (deg)
Flap handle position
Landing gear handle position

Pilot Control Forces

Captain's column force (lbs)
Captain's wheel force (lbs)
Captain's rudder force (lbs)
First officer's column force (lbs)
First officer's wheel force (lbs)
First officer's rudder force (lbs)

Control Surface Positions

Stabilizer position (deg)
Elevator position (deg) (each elevator)
Aileron position (deg) (each aileron)
Flaperon position (deg) (each flaperon)
Spoiler positions (deg) (each spoiler)
Rudder position (deg)
Flap trailing edge position
Slat leading edge position

Engine Parameters

N1 (% rated) (each engine)
EPR (each engine)
Net thrust (lbs) (each engine)

Environment

Ambient static pressure (PSF)
Ambient static temperature (deg. F)
Vertical wind (kts)
Wind speed (kts)
Wind direction (deg. true)

Autopilot/Automatic System Variables

Autopilot status (engaged/disengaged)
PF flight director switch status
PM flight director switch status
Autopilot pitch axis mode
Autopilot roll axis mode
Autothrottle status (engaged/disengaged)
Autothrottle mode
MCP selected altitude
MCP selected airspeed
MCP selected vertical speed (if active)
MCP selected heading (if active)
AOA for stall warning

APPENDIX 2:
HANDOUT PROVIDED BY THE ASIANA B777 TRAINING CAPTAIN

## Aisana Visual Approach

Condition #1 : Traffic Pattern Visual Approach

- FCTM 5.59-61, POM 2.18
- Condition : KSFO, 2NM downwind for RW28L, 1500ft, Flaps 5, speed 172kts
- FMC setup : RW28L ( /0070ft), VDI available, FIX page(RW28L: /2, /3, 194/ )
- Procedures

  . Abeam RW28L threshold : "Time check"

  . 30seconds"(PM) : "Gear down, F-20" [speed 152 set, S/B arm]

  . 45seconds"(PM) : "Checked, HDG 014 set, V/S -200~300 set, F-30" [speed 137 set]

  . "L/D checklist"

  . Look out for RW28L, adjust V/S with VDI, and set RWY heading when the trend vector meets the RWY extended centerline.

  . "Manual flight, "Both F/Ds off, PM side on"

  . "1000"(PM) : "Checked"

  . "500"(PM) : ""Stabilized"

Condition #2 : High Energy Visual Approach

- RNAV Visual Approach is recommended. (FCTM 5.26, POM 2.15.1.4)
- Condition : KSFO, 12NM final for RW28L, 6000ft, MDA 510ft set, Flaps 5, speed 180kts
- FMC setup : Select 'LOC RW28L' (No manual correction of waypoints)
- Procedures

. MCP ALT 1800ft set and Initiate descent with FLCH, S/B and Landing gear down (due to high altitude)

. LNAV : Check ISFO, LOC pointer and RNP

. Pitch mode change to VNAV (Preferred method in Asiana) : 'VNAV SPD'

. MCP ALT : 510ft set

. VNAV PTH : retract S/B and reduce speed

. FAF : "Passing FAF, 1800ft"

. After FAF : missed approach altitude set

. F-20, F-30, L/D checklist

. "1000"(PM) : "Checked"

. "Minimum" : "Landing, Manual Flight"

- F/Ds may not be turned off :
  - POM : page 2-128
  - FCTM doesn't mention about F/Ds off.

. "500"(PM) : ""Stabilized".